CONTROL VALVE FOR VARIABLE DISPLACEMENT COMPRESSOR

BACKGROUND OF THE INVENTION

The present invention relates to a control valve for controlling the displacement of a variable displacement compressor in a refrigeration cycle.

A variable displacement swash plate type compressor for use in a refrigeration cycle optionally varies the inclination angle of a swash plate or the displacement of the compressor by adjusting pressure in a crank chamber or a chamber for accommodating the swash plate, as disclosed in page 15 to 16 and FIG. 12 of Unexamined Japanese Patent Publication No. 2001-173556.

Namely, the compressor provides a control valve for adjusting the pressure in the crank chamber. The control valve, for example, varies the opening degree of a supply passage that interconnects a relatively high pressure region of the refrigeration cycle and the crank chamber. A relatively low pressure region of the refrigeration cycle and the crank chamber are interconnected through a bleed passage.

The opening degree of the control valve is adjusted to control a balance between the amount of relatively high pressure refrigerant gas introduced from

the relatively high pressure region to the crank chamber through the supply passage and the amount of refrigerant gas delivered from the crank chamber to the relatively low pressure region through the bleed passage. Thus, the pressure in the crank chamber is determined. The inclination angle of the swash plate is varied in accordance with the variation of the pressure in the crank chamber. As a result, the stroke of pistons, that is, the displacement of the compressor, is adjusted.

Recently carbon dioxide has been generally used as refrigerant for a refrigeration cycle in place of conventional chlorofluorocarbon. As carbon dioxide is used as refrigerant, pressure difference between relatively high and low pressures in a refrigeration cycle becomes much larger than that of chlorofluorocarbon (for example, 10Mpa). Accordingly, in the above structure that adjusts the displacement of the compressor by utilizing pressure difference in the refrigeration cycle, the refrigerant gas may flow through the inside of the control valve at relatively high speed based on the pressure differential generated in the refrigeration cycle.

As the refrigerant gas flows through the inside of the control valve at relatively high speed, erosion arises inside the control valve by fine foreign particles (for example, solid particles of 10 to 20 μm), which are contained in the refrigerant gas and cannot perfectly be removed by a filter. In view of the structure

of the control valve, erosion tends to arise around a portion for adjusting the opening degree of the control valve where the flow of refrigerant gas largely and intricately winds. Particularly, a seat surface of a valve seat and a valve surface of a valve body for opening and closing the control valve constitute a portion for adjusting the opening degree of the control valve. As flaw arises at the seat surface and the valve surface, refrigerant gas leaks through the flaw in a state when the control valve is fully closed, that is, the seat surface is in contact with the valve surface. As a result, the displacement of the compressor in a state when the control valve is fully closed is not maintained. Therefore, there is a need for a control valve that reduces the leakage of refrigerant gas in a state when the control valve is fully closed for a variable displacement compressor.

SUMMARY OF THE INVENTION

In accordance with the present invention, a variable displacement compressor optionally varies displacement based upon pressure in a crank chamber for adjusting the pressure in the crank chamber by varying an opening degree of a passage that interconnects the crank chamber and one of relatively high and low pressure regions of the refrigeration cycle. A control valve of the variable displacement compressor has a valve seat and a valve. The valve seat has a seat surface for adjusting the opening degree of the passage. The valve has a valve surface for adjusting the opening degree of the passage. At least one

of the seat surface and the valve surface is made of a material with relatively high hardness.

Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention that are believed to be novel are set forth with particularity in the appended claims. The invention together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

FIG. 1A illustrates a schematic view of a variable displacement swash plate type compressor and a longitudinal cross-sectional view of a control valve according to a preferred embodiment of the present invention; and

FIG. 1B illustrates a partially enlarged cross-sectional view of a adjacent portion for adjusting the opening degree of the control valve according to the preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A preferred embodiment of the present invention will now be described with reference to FIGs. 1A and 1B.

FIG. 1A illustrates a schematic view of a variable displacement swash plate type compressor 1 (hereinafter the compressor 1) for a refrigeration cycle of a vehicle air conditioner. The compressor 1 introduces refrigerant gas from a suction chamber 2 into a compression chamber 1a, then compresses the introduced refrigerant gas and discharges the compressed refrigerant gas to a discharge chamber 3 as the volume of the compression chamber 1a is varied by the rotation of a swash plate (not shown). An oil separator 4 is arranged near an outlet of the discharge chamber 3 for separating misty lubricating oil contained in the refrigerant gas from the refrigerant gas. Incidentally, carbon dioxide is employed as refrigerant for the refrigeration cycle.

In the compressor 1, a crank chamber 5, which accommodates the swash plate, communicates with the suction chamber 2, which is a relatively low pressure region in the refrigeration cycle, through a bleed passage 6. The oil separator 4, which is a relatively high pressure region in the refrigeration cycle, communicates with the crank chamber 5 through a supply passage 7. In the oil

separator 4, the lubricating oil separated from the refrigerant gas is supplied into the crank chamber 5 through the supply passage 7 together with a part of the refrigerant gas and lubricates sliding portions in the crank chamber 5. Namely, the supply passage 7 doubles as a feeding passage for feeding the lubricating oil separated by the oil separator 4 to the crank chamber 5.

Incidentally, a filter 8 is arranged at the upstream side (the side of the oil separator 4) of the supply passage 7 for removing foreign particles in the refrigerant gas. The filter 8 has a mesh size for only removing the foreign particles of 20 to 30 μm or above in view of interference against the flow of refrigerant gas.

A control valve CV is arranged in the supply passage 7 and optionally adjusts the opening degree of the supply passage 7. The adjustment of the opening degree of the control valve CV controls a balance between the amount of relatively high pressure refrigerant gas introduced from the discharge chamber 3 into the crank chamber 5 through the supply passage 7 and the amount of refrigerant gas delivered from the crank chamber 5 to the suction chamber 2 through the bleed passage 6. Thus, the pressure in the crank chamber 5 is determined. The inclination angle of the swash plate is varied in accordance with the variation of the pressure in the crank chamber 5 so that the displacement of the compressor 1 is adjusted.

For example, as the pressure in the crank chamber 5 reduces by decreasing the opening degree of the control valve CV, the inclination angle of the swash plate increases so that the displacement of the compressor 1 increases. On the contrary, as the pressure in the crank chamber 5 rises by increasing the opening degree of the control valve CV, the inclination angle of the swash plate reduces so that the displacement of the compressor 1 reduces.

The control valve will now be described.

As shown in FIG. 1A, a valve housing 10 of the control valve CV includes a valve body 11 on the upper side and an actuator housing 12 on the lower side in the drawing. Starting from the lower side of the drawing, a valve chamber 22, a communication passage 23 and a pressure sensing chamber 24 are respectively defined in the valve body 11. A valve rod 25 is movably arranged through the valve chamber 22 and the communication passage 23 so as to extend in the axial direction of the valve housing 10 (the vertical direction of the drawing). The upper end of the valve rod 25 inserted through the communication passage 23 separates the communication passage 23 from the pressure sensing chamber 24.

The communication passage 23 communicates with the oil separator 4 of the compressor 1 through the upstream portion of the supply passage 7. The

valve chamber 22 communicates with the crank chamber 5 of the compressor 1 through the downstream portion of the supply passage 7. The valve chamber 22 and the communication passage 23 constitute a portion of the supply passage 7.

As shown in FIGs. 1A and 1B, a valve portion 31 formed at the middle portion of the valve rod 25 is arranged in the valve chamber 22. In the valve body 11, a step between the valve chamber 22 and the communication passage 23 forms a valve seat 32, and accordingly the communication passage 23 forms a valve hole. As the valve rod 25 moves upward from a state where the communication passage 23 (the supply passage 7) is opened as illustrated in FIG. 1A to a state where the valve portion 31 reaches at the valve seat 32, a planar valve surface 31a of the valve portion 31 contacts on a planar seat surface 32a of the valve seat 32 so that the communication passage 23 (the supply passage 7) is closed. A coil spring 60 for urging the valve rod 25 is arranged in the valve chamber 22. The coil spring 60 urges the valve rod 25 in a direction in which the valve portion 31 leaves away from the valve chamber 32.

A bellows 33, which has a cylindrical shape, is accommodated in the pressure sensing chamber 24. The upper end of the bellows 33 is fixed to the valve housing 10. The upper end of the valve rod 25 is fitted to the lower end of the bellows 33. The bellows 33 has a bottom at one end and partitions the pressure sensing chamber 24 into a first pressure chamber 49 and a second

pressure chamber 50.

A fixed throttle 41 is provided in a discharge passage 40, which interconnects the discharge chamber 3 with an external refrigerant circuit (not shown). The first pressure chamber 49 communicates with the discharge passage 40 through a first pressure introducing passage 42 and connects at the upstream side (the side of the discharge chamber 3) relative to the fixed throttle 41. The second pressure chamber 50 communicates with the discharge passage 40 through a second pressure introducing passage 43 and connects at the downstream side relative to the fixed throttle 41. Accordingly, the bellows 33 reflects the variation of pressure difference between the upstream side and downstream side of the fixed throttle 41 for positioning of the valve rod 25 (the valve portion 31) as the lower end portion of the bellows 33 moves in accordance with the pressure difference. Incidentally, the bellows 33 moves the valve portion 31 in such a manner that the displacement of the compressor 1 varies to cancel the variation of the pressure difference between the upstream side and downstream side of the fixed throttle 41.

An electromagnetic actuator 51 is provided at the lower side of the valve housing 10. The electromagnetic actuator 51 provides a cylindrical accommodating cylinder 52 with a bottom at one end in the middle of the actuator housing 12. A center post 53, which has a columnar shape, is fixedly fitted to the

opening of the accommodating cylinder 52 on the upper side. This fitting of the center post 53 defines a plunger chamber 54 at the lowest portion of the accommodating cylinder 52.

A plunger 56 is accommodated in the plunger chamber 54 and is movable in the axial direction (the vertical direction of the FIG. 1A). A guide hole 57 extends through the center of the center post 53 in the axial direction of the center post 53. The lower side of the valve rod 25 is movably arranged in the guide hole 57. The lower end of the valve rod 25 is fixedly fitted to the plunger 56 in the plunger chamber 54. Accordingly, the plunger 56 and the valve rod 25 integrally move up and down anytime.

A coil 61 winds around the outer circumference of the accommodating cylinder 52 and partially covers an area from the center post 53 to the plunger 56. The coil 61 is supplied with electric power based upon a command of an air conditioner ECU (not shown). Accordingly, the magnitude of electromagnetic force (electromagnetic attraction) corresponding to electric power supplied to the coil 61 is generated between the plunger 56 and the center post 53. The electromagnetic force is transmitted to the valve rod 25 (the valve portion 31) through the plunger 56.

In the above control valve CV, the electromagnetic actuator 51 varies

electromagnetic force applied to the valve portion 31 in accordance with the electric power externally supplied so that a control target for pressure difference between the upstream side and downstream side of the fixed throttle 41 (set pressure differential), which is a reference for positioning action of the valve portion 31 by the bellows 33, is optionally changed. Namely, the control valve CV internally and autonomously positions the valve rod 25 (the valve portion 31) in accordance with the variation of the pressure difference so as to maintain the set pressure difference determined by electric power supplied to the coil 61. In addition, this set pressure difference is externally varied by adjusting electric power supplied to the coil 61.

As mentioned in the prior art, in the preferred embodiment where the displacement of the compressor 1 is adjusted by utilizing the pressure difference in the refrigeration cycle, the refrigerant gas may flow through the supply passage 7 at relatively high speed. Then, in the control valve CV that opens and closes the supply passage 7, the seat surface 32a of the valve seat 32 and the valve surface 31a of the valve portion 31, which are portions for adjusting the opening degree of the control valve CV, both are made of materials with relatively high hardness for protection against erosion.

Incidentally, the word of “a material with relatively high hardness” in the preferred embodiment means that a material with Vickers hardness of 500 or

above because pressure difference between relatively high and low pressures in the refrigeration cycle occasionally becomes approximately 10MPa and particles, which cause erosion are constituted of fine solid particles (10 to 20 μm) such as silicon oxide with relatively high hardness. The material of the valve seat 32 is brass and has Vickers hardness of approximately 200. Accordingly, to obtain a material of the seat surface 32a of the valve seat 32 with relatively high hardness, the surface of the material of the valve seat 32 is coated with a high hardness layer 32b by nickel-phosphorus plating. Thus, the seat surface 32a of the valve seat 32 is constituted of a relatively high hardness material with Vickers hardness of 500 to 800.

Additionally, the material of the valve rod 25 (the valve portion 31) is stainless steel (SUS) and has Vickers hardness of approximately 300. Accordingly, to obtain a material of the valve surface 31a of the valve portion 31 with relatively high hardness, the surface of the material of the valve portion 31 is coated with a high hardness layer 31b by salt-bath nitriding. Thus, the valve surface 31a of the valve portion 31 is constituted of a relatively high hardness material with Vickers hardness of 900 to 1100.

Incidentally, the thicknesses of the above high hardness layers 31b, 32b range approximately from a few μm to 1mm. The thicknesses of the high hardness layers 31b, 32b in FIG. 1B are exaggerated for easier understanding.

Also, the coil spring 60 is not shown in FIG. 1B.

According to the above preferred embodiment, the following advantageous effects are obtained.

(1) In the control valve CV, the seat surface 32a of the valve seat 32 and the valve surface 31a of the valve portion 31 are made of a material with relatively high hardness. Accordingly, even if foreign particles contained in the refrigerant gas collide with the seat surface 32a of the valve seat 32 and the valve surface 31a of the valve portion 31, they hardly arise flaws. Accordingly, the leakage of the refrigerant gas due to the flaws in a state when the control valve CV is fully closed reduces. As a result, the displacement of the compressor 1 corresponding to a state when the control valve CV is fully closed (maximum displacement in the preferred embodiment) is maintained.

(2) The high hardness layer 32b of the valve seat 32 is made of a material that is different from that of the high hardness layer 31b of the valve portion 31. Accordingly, a same-metal phenomenon is prevented between the seat surface 32a of the valve seat 32 and the valve surface 31a of the valve portion 31. The same-metal phenomenon means that mutually same metals lead to inconveniences such as an increase in coefficient of friction.

(3) The supply passage 7 doubles as a feeding passage for feeding lubricating oil separated by the oil separator 4 to the crank chamber 5. In the oil separator 4, foreign particles are also separated while the lubricating oil is separated from the refrigerant gas. Accordingly, for example, in comparison to the supply passage 7 that does not double as the feeding passage, the more foreign particles pass through the inside of the control valve CV. In the control valve CV, the seat surface 32a of the valve seat 32 and the valve surface 31a of the valve portion 31 are made of materials with relatively high hardness. Even when under the above hard condition, the leakage of the refrigerant gas is reliably reduced in a state where the control valve CV is fully closed. However, the present invention is embodied in a structure that the supply passage 7 doubles as the feeding passage for feeding the lubricating oil from the oil separator 4 to the crank chamber 5 so that the leakage of the refrigerant gas is much effectively reduced in a state when the control valve CV is fully closed.

(4) The compressor 1 is a refrigerant compressor for use in a refrigeration cycle, and carbon dioxide is employed as refrigerant for the refrigeration cycle. Accordingly, for example, in comparison to a state where chlorofluorocarbon refrigerant is used, pressure difference between relatively high and low pressures of the refrigerant in the control valve CV becomes much larger, and the flow speed of the refrigerant becomes much faster. As a result, the seat surface 32a of the valve seat 32 and the valve surface 31a of the valve portion 31 are easily

damaged due to the foreign particles. Namely, the present invention is embodied in the control valve of the carbon-dioxide-refrigerant compressor so that the leakage of the refrigerant gas is effectively reduced in a state when the control valve CV is fully closed.

The present invention is not limited to the embodiment described above but may be modified into the following alternative embodiments.

In an alternative embodiment to those of the above preferred embodiment, either of the seat surface 32a of the valve seat 32 or the valve surface 31a of the valve portion 31 is made of a material with relatively high hardness. In this state, the same advantageous effect to that of the paragraph (1) is obtained. That is, the leakage of the refrigerant gas is reduced in a state when the control valve CV is fully closed. However, obviously, both of the seat surface 32a of the valve seat 32 and the valve surface 31a of the valve portion 31, which are respectively made of materials with relatively high hardness, more reliably perform the above advantageous effect.

In the preferred embodiment, the seat surface 32a of the valve seat 32 is constituted of a material with relatively high hardness in such a manner that the material of the valve seat 32 is treated with surface hardening by nickel-phosphorus plating. In an alternative embodiment to those of the above

preferred embodiment, the surface hardening of the material of the valve seat 32 is selected from the group consisting of nickel plating, nickel-phosphorus-boron plating, nickel-boron plating, nickel-boron-tungsten plating, chrome plating and copper plating. Thus, the seat surface 32a is constituted of a material with relatively high hardness.

Also, the seat surface 32a of the valve seat 32 is not limited to be hardened with the surface hardening by plating but may be hardened by one of ion nitriding, gas nitrocarburizing and salt-bath nitriding. Thus, the valve surface 31a is constituted of a material with relatively high hardness.

Furthermore, the valve surface 31a of the valve portion 31 is not limited to be hardened with the surface hardening by nitriding. The valve surface 31a of the valve portion 31 may be hardened with the surface hardening of a material of the valve portion 31 by one of nickel plating, nickel-phosphorus plating, nickel-phosphorus-boron plating, nickel-boron plating, nickel-boron-tungsten plating, chrome plating and copper plating.

Alternatively, the material of the valve portion 31 (the valve rod 25) is steel for carburizing, and the surface of the material is hardened by carburizing so as to form the valve surface 31a with relatively high hardness.

In an alternative embodiment to those of the above preferred embodiment, the material of the valve seat 32 is not limited to brass but may be another copper series material, aluminum series material or stainless steel (SUS).

In the preferred embodiment, the control valve CV varies the opening degree of the supply passage 7 that interconnects the relatively high pressure region of the refrigeration cycle (the oil separator 4) and the crank chamber 5 so that the pressure in the crank chamber 5 is adjusted. Namely, the present invention is embodied in a so-called supply-side control valve, in which the control valve is arranged in the supply passage 7. In an alternative embodiment to those of the above preferred embodiment, a control valve varies the opening degree of the bleed passage 6 that interconnects the crank chamber 5 and the relatively low pressure region of the refrigeration cycle (for example, the suction chamber 2) so that the pressure in the crank chamber 5 is adjusted. Thus, the present invention is embodied in a so-called bleed-side control valve, in which the control valve is arranged in the bleed passage 6.

In the preferred embodiment, the control valve CV internally and autonomously positions the valve portion 31 in accordance with the variation of the pressure differential so as to maintain the set pressure differential determined by electric power externally supplied. Namely, the present invention is embodied in a so-called external control valve. However, the present invention is not limited

to be embodied in the external control valve but may be embodied in an internal control valve or a mere electromagnetic valve.

Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein but may be modified within the scope of the appended claims.